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**Air and Space Operations Center (AOC)  
Facility Design Guidelines:  
A Human Factors Engineering  
Perspective**

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**Interim Report for the period August 2005 to July 2006**

**Approved for public release;  
distribution unlimited**

**Air Force Research Laboratory  
Human Effectiveness Directorate  
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**THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR  
PUBLICATION.**

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## EXECUTIVE SUMMARY

The Air and Space Operations Center (AOC) weapon system (AN/USQ-163 FALCONER) is the operational level warfighting command center for air and space forces. The Falconer AOC is the senior element of the Theater Air Control System (TACS) and provides centralized command, planning, direction, control, and coordination of air, space and information operations. The AOC's various divisions and teams are responsible for planning, controlling, and assessing air and space operations. Through the AOC, the Combined/Joint Force Air and Space Component Commander (C/JFACC) directs tactical actions to produce desired operational and strategic effects in support of the Joint Force Commander's (JFC's) campaign. The fundamental principle of this system is centralized planning and control through the AOC, with decentralized execution by subordinate forces. The people who operate and maintain the AOC are the true foundation of the weapon system.

Because of the criticality of the users to the operations of the C2ISR weapon systems, LtGen Hobbins (SAF/XC) requested the AFC2ISRC/CCT to determine the status of human system integration in the C2 and ISR domains and to look for ways to improve its practice in the design of future C2ISR weapon systems. The Human Systems Integration (HSI) Tiger Team was formed in mid 2005 to respond to that tasking. One of the HSI Tiger Team's products provided inputs to Capabilities Description Documents for the Air and Space Operations Center (AOC) "Falconer" Weapon System and the Distributed Common Ground System (DCGS) "Sentinel" Weapon System. Based upon the value of these HSI inputs and the recognition that more AOCs were in the process of being designed, the team felt that more detailed guidance should be made available to weapon systems designers, especially for the human factors of facility design and layout.

This document addresses the human factors design aspects of users' workspace and the facility's habitability. The workspace covers the users' individual work environment (i.e., seats, desks, storage space, etc.) and the arrangements of the individual workspaces into team (i.e., cell) workspaces and into the larger aspect of the group (i.e., collections of cells) workspace. Workspace arrangement of teams and groups which facilitates collaboration has been shown to increase mission effectiveness and reduce manpower requirements in other U.S. weapon systems. Habitability factors are those living and working conditions that are necessary to sustain the health, comfort, safety, and morale of the users. Specifically addressed are the environmental factors of lighting, temperature, ventilation, humidity, and acoustical noise. Both the workspace and habitability factors directly contribute to personnel effectiveness, unit readiness, and mission accomplishment, and often preclude recruitment and retention problems. Most of the guidelines have been taken directly from the Military Standard 1472F, *Human Engineering*, and from the *Human Engineering Guide to Equipment Design*. Noteworthy examples of AOC designs are also given. These examples are observations by the Tiger Team or are "lessons learned" imparted to the Tiger Team from AOC experts.

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# INTRODUCTION

The Air and Space Operations Center (AOC) weapon system (AN/USQ-163 FALCONER) is the operational level warfighting command center for air and space forces. The Falconer AOC is the senior element of the Theater Air Control System (TACS) and provides centralized command, planning, direction, control, and coordination of air, space and information operations. The AOC's various divisions and teams are responsible for planning, controlling, and assessing air and space operations. Through the AOC, the Combined/Joint Force Air and Space Component Commander (C/JFACC) directs tactical actions to produce desired operational and strategic effects in support of the Joint Force Commander's (JFC's) campaign. The fundamental principle of this system is centralized planning and control through the AOC, with decentralized execution by subordinate forces. The people who operate and maintain the AOC are the true foundation of the weapon system. Thus, careful attention must be given to the design and layout of the facilities where these people perform their missions. While the facility should not be designed solely around optimum human factors, these factors cannot be systematically traded-off in support of other readiness elements without eventually degrading mission performance.

## SCOPE

This document addresses the human factors engineering (HFE) and habitability of user workspaces. The workspace covers the users' individual work environment (i.e., seats, desks, storage space, etc.), the arrangements of individual workspaces into a team workspace, and the organization of multiple team workspaces into a group workspace. Habitability factors are living and working conditions necessary to sustain the health, comfort, safety, and morale of the users. The HFE and habitability factors of the workspace directly contribute to personnel effectiveness, unit readiness, and mission accomplishment, and often preclude recruitment and retention problems.

This document does not address the human factors of the weapon system software applications nor the displays and controls that the users employ to perform their work. It also does not address the other domains of Human System Integration (HSI) (i.e., Training, Survivability, Environmental Safety & Occupation Health, Manpower, and Personnel) other than their intersections with Human Factors Engineering and Habitability.

## BACKGROUND

In mid 2005, the AFC2ISRC/CCT formed a Human Systems Integration (HSI) Tiger Team to respond to a SAF/XC tasker on the status of human system integration in the C2 and ISR domains and ways to improve its practice in the design of future C2ISR weapon systems. The HSI Tiger Team was lead by AFRL/HE with core membership from AFRL/IF, 311 HSW, ESC, and AFC2ISRC. Based upon the perceived value of the HSI inputs to the Capability Description Documents (CDD) for the Air and Space Operations Center (AOC) "Falconer" Weapon System and the Distributed Common Ground System (DCGS) "Sentinel" Weapon System, the Tiger Team felt that more detailed guidance for the human factors of facility design and layout should be made available to weapon systems designers. Thus, this report consolidates much of the detailed human factors guidance on issues directly relevant to facility design and layout.

# DESIGN GUIDELINES

Throughout this report, the source of the design guidance is given using the following notation: [x: y], where x is the document number as listed in the Reference section, and y is the chapter or paragraph number from the document. Unreferenced paragraphs represent the opinions of the authors based on their experience or comments from experienced AOC operators.

## WORKSPACE

### Individual Workspace

#### Work Surface

- *Dimensions.* A lateral work space not less than 48 inches wide shall be provided whenever practicable. Workspace depth should be a minimum of 16 inches deep. If a computer monitor is required on the work surface, then the work surface should be deep enough to allow the screen surface to remain (14–20 inches from the user’s eyeball. (Note: MIL-STD-1472F recommends a lateral work space of not less than 30 inches. However, since most AOC work spaces have multiple monitors, more lateral space is required.) [1: 5.7.3.1]

- *Height.* Desk tops and writing tables shall be 29–31 inches above the floor unless otherwise specified. For work that requires typing, the elbow should be at a 90° angle or even with the work surface. Typically this dictates a work surface height of 26–31 inches. Users may adjust seating height to accommodate this elbow/forearm position and utilize a foot rest if necessary. [1: 5.7.3.1]

- *Materials.* The work surface shall be a smooth, hard writing surface. Consider using surface materials that are not cold to the touch. AOC rooms are typically cool; air conditioning keeps the computers and servers in good thermal ranges, so many users complain that their work surfaces are always cold.

- *Seating.* Seating shall allow the users to perform their mission functions without degrading their performance capability in alertness, cognition, strength or dexterity and without significant or lasting pain or injury. The seating should accommodate users within the 5<sup>th</sup>–95<sup>th</sup> percentile in stature. [1: 5.7.3.4]

- *Seat pan and vertical adjustment.* The seat pan shall have an adjustable height of 15 to 21 inches with increments of no more than 1 inch each. If the seat height exceeds 21 in, a footrest shall be provided. The seat pan shall have a 0°– 7° adjustable tilt rearward, be between 15–18 inches wide, and shall be not more than 16 inches deep. [1: 5.7.4.2]

- *Backrest.* A supporting backrest that reclines 100° - 115° shall be provided. The backrest shall engage the lumbar and thoracic regions of the back, and shall support the torso in such a position that the operator’s eyes can be brought to the “Eye Line” with no more than 3 inches of forward body movement. The backrest width shall be 12–14 in. [1: 5.7.4.3]

- *Cushioning and upholstery.* Where applicable, both the backrest and seat shall be cushioned with at least 1 inch of compressible material. Upholstery shall be durable, non-slip, and porous. [1: 5.7.4.4]

- *Armrests.* Armrests shall be at least 2 inches wide and 8 inches long. Arm rests should be padded and at a height that allows elbows to be at one’s side. In addition, arm rests must be recessed such that the user can easily pull up to the work surface and work with elbows at approximately 90° angles. [1: 5.7.4.5]

- *Seat base.* Chairs shall have at least four supporting legs. Swivel chairs should have five supporting legs. The diameter of the seat base of swivel type chairs should be 18 inches. [1: 5.7.4.6]
- *Knee room.* Knee and foot room not less than 25 inches high, 20 inches wide, and 18 inches deep shall be provided beneath work surfaces. [1: 5.7.3.5]

#### Individual Desktop Monitor(s)

- *Multiple Monitors.* If multiple desktop monitors (at the same security classification level) are present, then a single keyboard and mouse should be used to control the multiple screens. The screens should be placed as close together as possible to give the appearance of one large screen.
- *Position.* The top of the screen should be at or below eye level so operator looks slightly down at the screen. The operator should not have to tilt back to look at any parts of the screen. People with bifocals have particular trouble with this, so it is best for them to position their monitor screens very low. Monitor(s) should be directly in front of the user, not to the side. Side positioning may cause neck strain. Users should keep an arm's length away from the front of the monitor. Also keep an arm's length away from the backs and sides of other members' monitors.
- *Glare.* To reduce glare and eyestrain, the monitor should be positioned at right angles to light emitting sources. Glare screens should be used as a last resort.

Workspace Lighting. Lighting levels should be about 50 footcandles. Task lighting should be used if more light is needed in the work areas. Indirect lighting is best; parabolic lenses with fluorescent fixtures are also good.

Cabling. Today's workspaces are characterized by large numbers of cables (i.e., power, video, audio, and data). If modular furniture is used, ensure that the existing cable routing conduits are large enough to handle the current cable volume, while allowing extra volume for new cables as well as easy accessibility for the maintainers. If tables/desks are used, ensure that cables are sufficiently bundled together so that tripping hazards do not exist. If possible, cabling between aisles should be routed underneath false floor. If routed over the floor, then the entire cable run in the aisle should be completely enclosed and appropriately marked to avoid a trip hazard.

Storage Space. Adequate space shall be provided in the immediate work space to store manuals, worksheets, and other required materials, including an airman's basic combat protective gear, if issued. [1: 5.7.1.3.4]

### **Team Workspaces**

Team Layout. Workspaces for teams (i.e., cohesive collection of individuals working a common task; a cell) should be designed to facilitate communications among the team members.

- *Analysis*<sup>1</sup>. Link analyses allow determination of optimal locations for specific elements based upon minimizing the space between the communication elements such as distance (movement), reach, visual scanning, and auditory. Task analyses and cognitive work analyses can be used to identify which team members should be located near each other based on their work and degree of collaboration needed for decision making. [7, 8, 9]

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<sup>1</sup> Detailed information on the three analysis methods suggested here, as well as many others, can be found in references 7, 8, and 9.

- *Co-location.* The layout of team workspaces should allow for co-located team members to maintain eye contact, and where possible, should be close enough to allow effective verbal communication among team members.
- *Flexibility.* The layout design and furniture shall be flexible to allow for efficient operation, minimize walking from one station to another, and allow for quick reconfiguration as new requirements emerge.
- *Special Needs.* Due to the specific work requirements of some teams, extra tools (and floor space) are often required to facilitate work.

The following are samples of specific work requirements that impact a team's physical space needs. These are a representative list based on our Tiger Team's AOC observations:

- *Team Collaboration.* Some team functions (i.e., brainstorming, reasoning, etc.) need the rich communication bandwidth currently provided only by face-to-face collaboration and interaction with group tools (e.g., white boards, flip charts, smart boards, etc.) As required, additional floor space shall be provided for small groups (typically 3-5 people) and their associated group tools.
- "Quiet" Space. Some team functions (i.e., brainstorming, reasoning, etc.) require a high degree of focusing on a problem without the visual and auditory distractions typically found on the AOC. As required, provide a separate "quiet" space (i.e., room, partitioned area, etc.) shall be provided that allows the necessary degree of privacy for especially critical or sensitive topics.

Note: At both JEFX 04 and 06, the Strategy Division co-located part of their team to areas outside of their assigned space so they could have "quiet" space. Even though this location was outside of the main CAOC-N building, the benefits of having such a space outweighed its physical inconvenience.

- *Small Group Displays.* Many teams need small group displays (e.g. 50" plasma/LCD displays) that provide a team coordination/synchronization function, allowing team members to see the overall status of their team's task. If such a team coordination function is required, then the small group display shall be located within eyesight of the team members.

## **Group Workspace**

Group Layout. Groups of teams are located together to jointly share a common area. The physical location and arrangement of groups should be determined in accordance with the following principles: [3: 10.4.1]

- Locate closely related teams in a single building, on a single floor if possible.
- Arrange teams according to a plan of work flow (e.g. link analysis).
- Integrate related activities in accordance with actual requirements for interaction. Don't separate activities simply because the work is different.
- When noise or special lighting requirements are a problem, use partitions between related activities.
- Where noise or lighting is not a problem, related activities may be separated by space rather than partitions (where space is available).
- Provide face-to-face access for related teams.
- Integrate working areas that are closely related; do not separate arbitrarily by storage space, equipment, etc.

- Give a central location to a team that has many contacts with other teams.
- Provide privacy for supervisors.
- Locate supervisors so they can readily contact subordinates or subgroup supervisors
- Integrate supervisory locations of closely related subgroups.
- If supervisors need to be able to establish eye contact with personnel from various teams and to see what the teams are doing, consider a raised flooring “crows nest” work area for the supervisor. Having the supervisor elevated also makes it easier for team members to get the attention of the supervisor.

#### Traffic spaces

- *Aisle widths.* A minimum clearance of 4 ft between a table/desk edge and the nearest wall or table will provide a 2 ft aisle when people are seated at the table. If people are seated back-to-back, then a clearance of 6 ft between tables is recommended, resulting in a 2 ft aisle. At a minimum, provide at least a 5 ft clearance between tables. The minimum clearance provides a 1 ft path, which requires most people to turn sidewise and slide through. [3: 10.7]

- *Corridor widths.* Corridors must be able to accommodate the passage of large equipment with inflexible dimensions and the free flow of personnel. To accommodate two people passing, the recommended width is 54 inches (44 inches minimum); and to accommodate three persons abreast, the recommended width is 72 inches (50 inches minimum). [3: 10.7]

- *Aisle/Corridor general recommendations* [3: 10.7]

- Avoid blind corners
- Locate paths for minimum distances, using flow charts or diagrams to indicate where the densest traffic will be.
- Make intersections converge at 90° to minimize lost floor space.
- Keep aisles clear; do not allow equipment or structural-support columns to protrude into any aisle.

Signage. If a large number of people are working in the group area containing multiple teams, particularly if many of the people are new or transient, then appropriate signage should be placed in a visible location that clearly identifies the name of the team. Clearly marked floor maps (i.e., “You Are Here” maps) should be located on the walls identifying team locations.

#### Example Group Layouts

- At the 8AF AOC (Barksdale AFB), the Strategy Division is collocated with the ISR Division in the SCIF. This allows Strat easy access to necessary data as they discuss and develop the complete (high side – low side) Joint Air Estimate Plan (JAEP) and full operational assessment picture. Note: Special attention must be paid in this layout since the Strategy team frequently contains coalition team members who do not have full access to SCIF protected data.
- At the 8AF AOC (Barksdale AFB), parts of ISR Division were located between Combat Operations and Combat Plans. This layout was intended to facilitate easy access to the necessary intel data (after classification downgrading) and to the intel personnel who can provide additional explanation on the data meaning and context.
- At CAOC-X (Langley AFB), a BattleCab area was located on the 2<sup>nd</sup> floor for the senior flag officers. This offers them a private area for their discussions and a separate conference room for their numerous VTCs. From this vantage point they can easily see the large wall screens, as well as, easily observe the Combat Ops floor and sense the pace of the war without disrupting the normal ops flow.

## Large Screen Displays

### General

- *Use.* Large-screen displays may be used under the following conditions: [1: 5.2.5.1.1]
  - A group of operators frequently refers to the same information and is required to interact as a team, based on the same information.
  - One or more members of a team of operators must move about, yet must frequently refer to information required to make decisions— information they cannot carry with them or do not have displayed at their assigned position(s) should be displayed.
  - Space or other constraints preclude the use of individual displays for each team member to call up commonly-used information.
  - It may be desirable to have general information available to persons who should not interrupt on-going group operations by looking over the shoulder(s) of individual operator(s) to see individual displays.
- *Avoidance.* Large-screen displays shall be used only when the spatial and environmental conditions allow satisfactory observational geometry to ensure that all critical operators have visual access in terms of viewing distance, angle and lack of interference from intervening objects, personnel or ambient lighting. If the display is optically projected, see following paragraph on optical projection. [1: 5.2.5.1.2]
- *Viewing distance.* The display shall not be placed further from an observer than will provide appropriate resolution of critical detail presented on the display. The display shall not be closer to any observer than 1/2 the display width or height, whichever is greater. [1: 5.2.5.1.3]
- *Physical interruption of view.* A large screen display shall not be located with respect to critical observers so that the view of the display is obscured regularly by persons moving in normal traffic patterns. [1: 5.2.5.1.4]
- *Control of displayed information.* Control of large-screen group display systems shall ensure that critical information cannot be modified or deleted inadvertently or arbitrarily. Changes in the group display shall be controlled by designated operators who operate according to pre-established procedures, the command of a person in charge, or both. When an individual must make changes that are of interest only to him or her, a separate display shall be provided. [1: 5.2.5.1.5]

### Direct View Large Wall Screens

- *Character height.* The height of letters and numerals should be not less than 5.8 mrad (20 min) of visual angle, and shall be not less than 10 min of visual angle from the longest anticipated viewing distance. Note: Some references recommend a minimum visual angle of 12-16 min, with 20-22 min being preferred. [1: 5.2.5.2.1]
- *Character width.* Character width should be approximately 0.9 of the height. [1: 5.2.5.2.2]
- *Luminance contrast.* Standard and large characters (i.e., >20 min) of visual angle, as measured from the longest anticipated viewing distance, should have a luminance contrast of not less than 1.5:1. [1: 5.2.5.2.3]
- *Polarity.* Where feasible, dark characters should be displayed on a light background unless the background appears to flicker. [1: 5.2.5.2.4]
- *Background for colored objects.* If the display includes color-coded objects, the background should be a neutral color such as gray. [1: 5.2.5.2.5]

### Optical projection

- *Use.* Providing ambient light can be properly controlled, optical projection displays are suitable for applications requiring group presentation, pictorial and spatial information, past history vs. real-time presentation, synthetically generated pictures, simulation of the external world, and superposition of data from more than one source. Rear projection shall be used where physical obstructions to front projection impair viewing or where work areas require high ambient illumination for other activities. [1: 5.2.5.3.1]

- *Seating area.* Viewing distance/image width relationship and off-center viewing of optical projection displays for group viewing should conform to the preferred limits of Table 1 and shall not exceed the acceptable limits indicated. For individual viewing from a fixed location, off-centerline viewing shall not exceed 10°. [1: 5.2.5.3.2]

- *Image luminance and light distribution.* Image luminance and light distribution should conform to the preferred limits and shall not exceed the acceptable limits of Table 1. The screen center luminance at the maximum viewing angle shall be at least half its maximum luminance. [1: 5.2.5.3.3]

FACTOR	OPTIMUM	PREFERRED LIMITS	ACCEPTABLE LIMITS
Ratio of VD/SD where VD = Viewing Distance; SD = Screen Diagonal	4	3-6	2-8
Angle off centerline	0°	20°	30°
Image luminance (no film in operating projector)	35 cd/m2* (10 ft-L)	27-48 cd/m2* (8-14 ft-L)	17-70 cd/m2* (5-20 ft-L)
Luminance variation across screen (ratio of maximum to minimum luminance)	1.0	1.5	3.0
Luminance variation as a function of viewing location (ratio of maximum to minimum luminance)	1.0	2.0	4.0
Ratio of AL/BI where AL = Ambient Light; BI = Brightest part of Image	0	0.002-0.01	0.1 max**
* For still projections higher values may be used			
** For presentations not involving gray scale or color (e.g., line drawings, tables) 0.2 may be used.			

**Table 1. Group viewing of optical projection displays**

- *Legibility of projected data.*

- *Style.* A simple style of numerals and letters shall be used. Stroke width shall be 1/6 to 1/8 of numeral or letter height, but may be narrower for light markings on a dark background. Stroke width shall be the same for all letters and numerals of equal height. [1: 5.2.5.3.4.1]

- *Size.* The height of letters and numerals shall be not less than 10 minutes and should be not less than 15 minutes of visual angle, as measured from the longest anticipated viewing distance. [1: 5.2.5.3.4.2]

- *Contrast.*

- *Luminance ratio.* Under optimal ambient lighting conditions, the luminance ratio should be 500:1. The luminance ratio for viewing charts, printed text and other line work via slides or opaque projectors shall be not less than 5:1. For projections that are limited in shadows and detail, such as animation and photographs with limited luminance range, the luminance ratio shall be not less than 25:1. For images that show a full range of colors (or grays in black-and-white photographs), the luminance ratio shall be not less than 100:1. [1: 5.2.5.3.4.3.1]

- *Direction of contrast.* Contrast may be either light on a dark background or vice versa, except where superposition is used. For subtractive superposition (at the source), data shall be presented as dark markings on a transparent background. For additive superposition (at the screen), data shall be presented as light markings on an opaque background. The use of colored markings against colored backgrounds of comparable brightness shall be avoided. [1: 5.2.5.3.4.3.2]

- Alignment. Mis-registration of superimposed alphanumeric data or symbols shall be minimized. [1: 5.2.5.3.4.3.4]
- Keystone effects. The projector-screen arrangement shall minimize keystone effects (distortion of projected data proportions due to non-perpendicularity between projector and screen). [1: 5.2.5.3.4.3.5]

## ENVIRONMENT

### Lighting

General. General and supplementary lighting shall be used as appropriate to ensure that illumination is compatible with each operator and maintainer task situation. Illumination requirements for office tasks (e.g., reading small type and handwritten reports and doing so over prolonged periods) typically have a recommended luminance level of 70 foot-candles (minimum: 50 foot-candles). However, problems with reflected glare or undesirable brightness contrasts when using large wall displays may require lower levels of illumination. In such cases, individual task lights should be provided for personnel in the affected areas to bring the illumination up to the recommended levels. Illumination sources should be distributed so as to reduce both direct and reflected glare. Light sources should not have a perceptible flicker. [1: 5.8.2.1.1]

Glare. One of the most serious illumination problems is glare or dazzle from surfaces. Relatively bright light shining into the observer's eyes as the observer tries to view a relatively dim visual field is a common cause of reduced performance in visual tasks. Reflected glare not only reduces visibility for objects in the field of view, but causes visual discomfort. [2: 5.8.2.5.1]

- *Direct glare.* Direct glare arises from a light source within the visual work field. Direct glare should be controlled by avoiding placing bright light sources within 60° of the center of the visual field. Since most visual work is at or below the eye's horizontal position, placing luminaries high above the work area minimizes direct glare. Using indirect lighting and more relatively dim light sources, rather than a few very bright ones as well as using polarized light, shields, hoods, or visors to block the glare in confined areas will also reduce glare. [2: 5.8.2.5.2]

- *Reflected glare.* Reflected glare refers to reflections from shiny surfaces in the visual field. Reflected glare should be controlled by using surfaces that diffuse incident light, rather than reflecting it specularly and arranging direct-light sources so their angle of incidence to the visual work area is not the same as the operator's viewing angle. To avoid display faces' or eyeglasses' reflecting glare into the operator's eyes, bright light sources should not be placed behind operators. [2: 5.8.2.5.3]

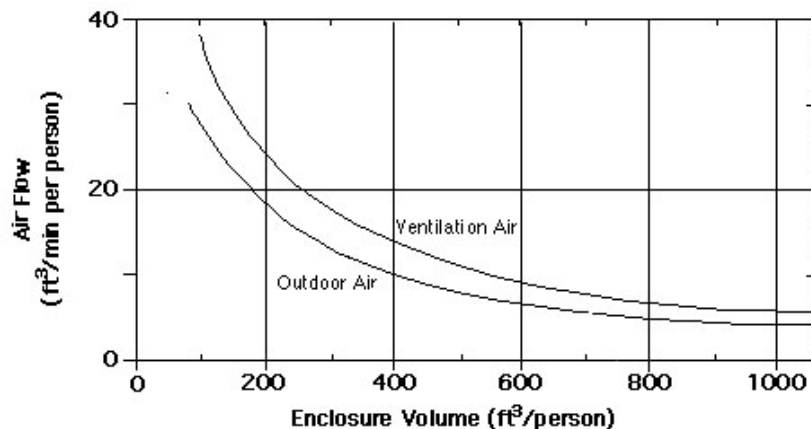
### Temperature.

Within permanent and semi-permanent facilities, provisions shall be made to maintain a temperature not less than 65°F or more than 85°F. Neither hot nor cold air shall be directly discharged on personnel. The temperature of the air at floor level and at head level at any personnel position should not differ by more than 10°F. [1: 5.8.1.1, 1: 5.8.1.3, 1: 5.8.1.5]

### Ventilation.



Adequate ventilation shall be assured by introducing fresh air into any personnel enclosure. If the enclosure volume is 50 ft<sup>3</sup> or less per person, a minimum of 30 ft<sup>3</sup> of ventilation air per minute shall be introduced into the enclosure; approximately two-thirds should be outdoor air. For larger enclosures, the air supply per person may be in accordance with the curves in Figure 1. Air shall be moved past personnel at a velocity not more than 100 ft per minute — 65 ft per minute if possible — to preclude pages in manuals from being turned by the air or papers from being blown off work surfaces. Under NBC conditions, ventilation requirements shall be modified as required. Ventilation or other protective measures shall be provided to keep gases, vapors, dust, and fumes within the Permissible Exposure Limits specified by 29 CFR 1910 and the limits specified in the American Conference of Governmental Industrial Hygienists Threshold Limit Values. Intakes for ventilation systems shall be located to minimize the introduction of contaminated air from such sources as exhaust pipes. [1: 5.8.1.2]



**Figure 1. Ventilation Air Flow Requirements for Specified Enclosure Volume**

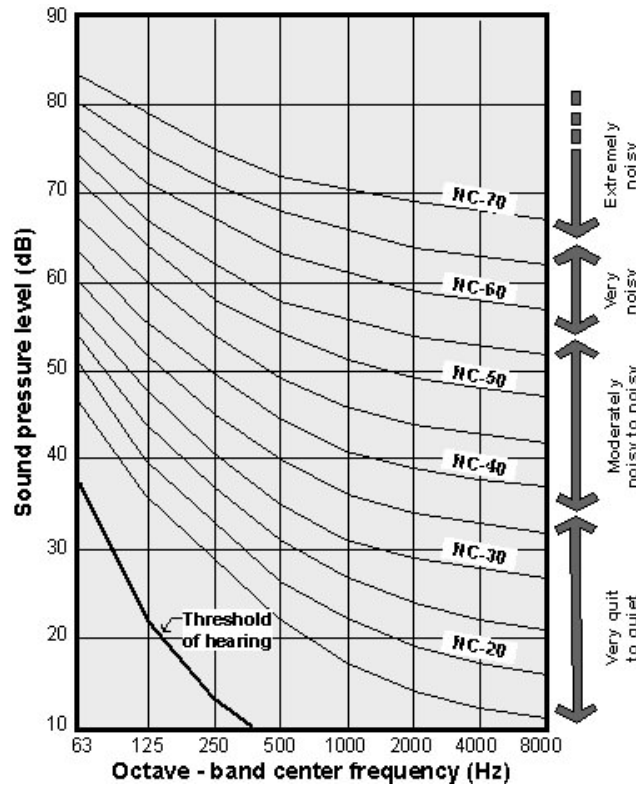
### **Humidity.**

Approximately 45% relative humidity should be provided at 70°F. This value should decrease with rising temperatures, but should remain above 15% to prevent irritation and drying of body tissues (e.g., eyes, skin, and respiratory tract). Relative humidity above 30% and below 70% is considered adequate if the optimum temperature range for physical comfort is maintained. [1: 5.8.1.4, 2: 5.8.4.4.2.f]

### **Acoustical Noise.**

General. Workspace noise shall be reduced to levels that permit necessary direct (person-to-person) and telephone communication and establish an acceptable acoustical work environment. Criteria for workspaces are defined by either A-weighted sound level (dBA) or the Noise Criteria curves. The Noise Criteria (NC) is a single numerical index commonly used to define design goals for the maximum allowable noise in a given space. The Noise Criteria consist of a family of curves that define the maximum allowable octave-band sound pressure level (SPL) corresponding to a chosen NC design goal. Although alternate contours have been proposed (most notably the room criterion or RC curves), the NC curve remain the most widely accepted. They primarily apply to the noise produced by a ventilation system, but they may be applied to other noise sources. They can also be used to specify the steady, or continuous background noise levels needed to help achieve satisfactory sound isolation, provided levels are 4 to 5 dB below the NC curve at both the low and high frequencies. Each NC curve is defined by its sound pressure

level over eight octave-band center frequencies shown on the Figure 2. Specific auditory communication requirements with respect to sound pressure levels (dBA) are listed in Table 2. [1: 5.8.3.3, 5: Chap 43]



**Figure 2. Sound Pressure Curves for Specified Noise Criteria Design Goal**

Communication Requirement	Recommended Maximum Noise Level
Occasional telephone use or occasional direct communication at distances up to 5 ft.	75 dB(A)
Frequent telephone use or occasional direct communication at distances up to 5 ft	65 dB(A)
No difficulty with telephone use or occasional direct communication at distances up to 15 ft	55 dB(A)
No difficulty with direct communication	45 dB(A)

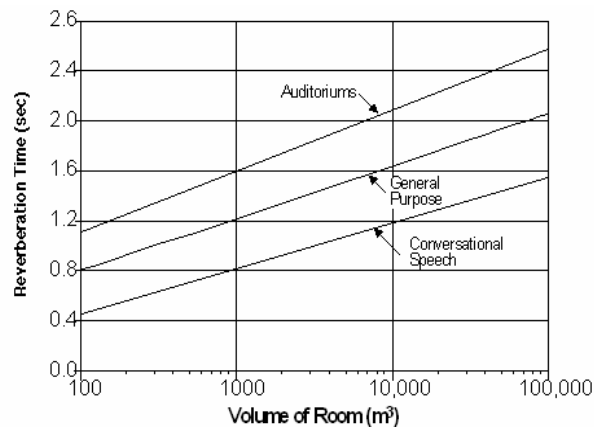
**Table 2. Auditory Communication Requirements and Sound Level Relationships**

### Workspace Noise Guidelines.

- *Acoustic design* The workspace or facility design shall minimize the ambient noise level to the extent feasible through effective sound reduction or attenuation to meet the criteria herein. It is recommended that an acoustical architectural design firm be consulted during the design and planning phases of the facility. [1: 5.8.3.4.1]

- *Attenuation by materials and layout.* Acoustic materials with high sound-absorption coefficients should be provided as necessary in the construction of floors, walls, and ceiling to provide the required sound control. Excessive reverberation in rooms and work stations may be controlled by applying sound absorbing materials on floor, ceiling tiles, and special wall treatments. In the physical design and layout of rooms and work stations, excessive noise should be attenuated by such means as staggered construction of walls, staggering of doors in corridors or between rooms, use of thick-paned or double-paned windows, and use of sound-attenuating partitions. [1: 5.8.3.4.2]

- *Reduction of reverberation time.* Where speech communication is a consideration, the acoustical treatment of facilities should be sufficient to reduce reverberation time below the applicable limits of Figure 3. [1:5.8.3.4.1]



**Figure 3. Range of Acceptable Reverberation Time**

- *HVAC systems considerations.* Building design and construction must include engineering controls for HVAC equipment to limit objectionable noise and vibration levels. Noise and vibration control design for HVAC systems should start during the schematic and design development phases and continue throughout the entire process. Postponing the acoustical design until the end of the working drawings phase does not allow for proper integration of all components to ensure the system design goals are met.

## **CREW SUPPORT AREAS**

### **Break Room.**

A break room or lounge should be provided for users to take short breaks. The intense activities within the AOC during exercises and crisis situations generate personnel fatigue, making a break room necessary to separate personnel from their normal monitoring, communications, planning, and decision making work. The room should be equipped with a kitchenette with refrigerator, range, sink, countertop space for food preparation, coffee and soda machines, canteen/snack area, dining chairs and tables, lounging area with comfortable chairs, bulletin boards, and computer terminals with NIPRnet access. The break room should provide both a physical and mental separation from the AOC. This may be achieved

with changes in the color schemes, the décor, and furnishings. The space should provide personnel with the options for relaxing alone and in small groups around tables or in more comfortable chairs and sofas.

#### **Restrooms.**

Adequate restroom facilities are necessary. For businesses, the international plumbing code requires 1 lavatory per 80 people and 1 water closet per 50 people. (Note: For males, urinals may be at least 50% of the total number of required water closets.) These shall be distributed proportionately between the sexes, based on the occupancy load. The occupant load shall be composed of 50% of each sex, unless statistical data indicates a different distribution of the sexes. [6: Sections 403.2, 419.2]

## **SUMMARY**

These design statements are guidelines. They are not requirements. When considered individually, their implementation may be straightforward. However, when several must be considered collectively, there may be instances when the guidance conflicts. In these cases, the facility designer should consult with relevant HSI domain specialists and with the system users; and may need to develop mock-ups, prototypes, simulations, and analyses, in order to determine the specific resolution of guideline interactions. Proper application of these HFE and habitability guidelines can produce effective and efficient workspace that help focus the AOC operators on their most important work – planning, coordinating, directing, controlling, and assessing air, space, and information operations.

## REFERENCES

1. Military Standard 1472F (MIL-STD-1472F), *Human Engineering*, Department of Defense, Washington D.C., 23 August 1999
2. Military Standard 759C (MIL-STD-759C), *Handbook for Human Engineering Design Guidelines*, Department of Defense, Washington D.C., 31 July 1995
3. *Human Engineering Guide to Equipment Design*, Department of Defense, Washington D.C., 1972
4. *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations*, ANSI/HFS 100-1988, Human Factors Society Inc, 4 February 1988
5. *Handbook of Acoustical Measurements and Noise Control*, Harris, C.M. Third Edition, 1999, McGraw-Hill
6. *International Plumbing Code*, International Code Council, Falls Church, VA, 2003
7. *Human Factors Methods: A Practical Guide for Engineering and Design*, Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., and Jenkins, D.P., Ashgate Publishing Company, Aldershot, UK, 2005
8. *Cognitive Task Analysis*, Schraagen, J.M, Chipman, S.F., and Shalin, V.L., Lawrence Erlbaum Associates, 2000
9. *Handbook of Cognitive Task Design*, Hollnagel, E., Lawrence Erlbaum Associates, Mahwah, NJ, 2003